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Integration of stakeholder choices and multi-criteria analysis to support land use planning in semiarid areas[1]

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1. Introduction

Ecosystems provide a variety of benefits, known as ecosystem services, which are vital for sustaining economic growth and human wellbeing, and alleviating poverty (MEA, 2005; Turner and Daily, 2008). The ecosystem services concept has gained growing interest as a key tool in environmental policies (Fisher et al., 2009; Braat and de Groot, 2012; Müller and Burkhard, 2012). In land use planning, the application of this concept provides decision makers with arguments regarding the choice of suitable options to achieve environmental and social goals (McKenzie et al., 2014). However, land use decisions often focus on achieving one or a few ecosystem services (Tallis et al., 2008; Fu et al., 2015). For instance, in forestry and agricultural interventions, many services such as those related to water and carbon cycles, aesthetics and biodiversity are often omitted (Cortina et al., 2011). There is still a need for land use strategies that address the full spectrum of services provided by ecosystems including both market goods and non-market services (Bateman et al., 2013).

Studies focused on operational implementation of the ecosystem services approach highlight the critical requirement for integrating a wide range of stakeholders (Ruckelshaus et al., 2015; Van Wensem et al., 2017). The term “stakeholder” refers to those people who will be affected or may have some influence on a decision (Freeman, 1984; Wilcox, 2003). Stakeholders may equally include local natural resource users, political and administrative decision makers, members of non-government organizations, and expertise providers (Spangenberg et al., 2015). These groups may have various and sometimes conflictive social needs and demands regarding ecosystems (Hein et al., 2006; Menzel and Teng, 2009; Seppelt et al., 2011). The explicit consideration of potential agreements and disagreements between stakeholders is likely to improve the likelihood of successful project implementation (Primmer et al., 2015).

Multi-criteria analysis (MCA) is a suitable tool for participative planning that enhances environmental decision making processes (Mendoza and Martins, 2006). MCA has desirable characteristics that make it appropriate for land use planning based on ecosystem services: it offers the possibility to consider both marketable and no marketable goods and services, it can incorporate a mixture of quantitative and qualitative information, and it allows the visualization of the opinion of different groups of stakeholders (Qureshi et al., 1999; Mendoza and Prabhu, 2000). Through a MCA, it is a possible to obtain a classification of a set of land uses according to their contribution to the provision of vital ecosystem services (Koschke et al, 2012; Fontana et al., 2013). However, like other models, MCA represents a simplification and an abstraction from the real system (Munda, 2004), and operational validity is needed to check for the agreement between MCA outputs and the real system (Dodgson el al., 2001). Many studies dealing with participative MCA used the opinion of scientists and practitioners as a basis for validation (Qureshi et al., 1999; Paracchini et al., 2009), but few studies have crossed MCA output with direct stakeholder choices. In land use planning, stakeholder validation may allow checking if the highly scored land use options resulting from MCA indeed correspond to those favored by stakeholder groups.

Collective validation of MCA results through constructive dialogue can be useful for promoting reciprocal learning, and represents a valuable contribution to deliberative democracy (Munda, 2004; Zhang et al., 2012). However, practical cases of collective

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validation are scarce, especially in developing countries in which stakeholders, mostly local ones, are considered as sources of information and passive recipients of top-down decisions, rather than influential actors.

In response to these concerns, our study provides a structured tool for decision-makers to make choices on land use options, bridging scientific data and comprehensive social aspirations. The main objectives of this study are: (i) to assess vital ecosystem services provided by different land use types in a semiarid area of northern Morocco, (ii) to determine the most suitable land use options for human well-being using a participative MCA, and (iii) to propose a framework for land use planning considering MCA results and stakeholder choices.

1. Methods

1.1. Study area

The study area corresponds to Béni Boufrah catchment (34°58'-35°10'N; 4°14'-4°25'W). It is located in the Central Rif Mountains, 55 km W of Al Hoceima (northern Morocco, Fig. 1). The catchment is 21 km long, from Jbel Izoural (1700 m) to the Mediterranean coast, and covers an area of 16,300 ha. Climate is semiarid Mediterranean with irregular and often stormy rainfall. Socio-demographic conditions are disadvantageous, showing high demographic density and serious problems of poverty, illiteracy and rural exodus (Moroccan General Census, 2014; Forest Administration of NE Morocco, 2012).

The main productive activity is agriculture dominated by rainfed cereals, mainly barley and wheat, and fruit trees, mostly almond and olive. Agricultural yields are low as a consequence of land fragmentation, rough terrain, high soil stoniness, and lack of irrigation and mechanization (Al Karkouri, 2003; Forest Administration of NE Morocco, 2012). An emerging agricultural activity is linked to a cactus cultivar (*Opuntia ficus-indica* (L.) Mill. var. *Dellahia*) which has gained an increasing economic and cultural value. Animal husbandry, based on sheep and goats, has decreased in the last decades as a result of droughts, rural exodus and abandonment of traditional agro-pastoral systems. The area hosts other economic activities such as sea fishing, harvesting of aromatic and medicinal plants, beekeeping and eco-tourism. These activities are seasonal, and produce low monetary incomes.

Natural forests in Béni Boufrah are mostly dominated by Barbary Red Cedar (*Tetraclinis articulata* Vahl Masters) and Holm oak (*Quercus ilex, subsp. ballota*; Fig. 1). These forests have faced high human pressure for a long time, mainly illegal cutting and expansion of agricultural land (Pascon and Wusten, 1983). Forest decline, combined with harsh biophysical conditions, led to serious problems of land degradation, including large scale soil erosion, flooding and depletion of soil fertility (Aboulabbes et al., 2005). To combat land degradation, the Moroccan Administration implemented several forest and agricultural actions. The most significant ones were undertaken within the framework of the DERRO project (Economic and Rural Development of the Western Rif, 1961-1972), whose main objective was to shift the Rif's population away from traditional agriculture and grazing, towards more productive and sedentary modes of living (Perry, 2014). Implemented actions mainly included afforestation with *Pinus halepensis*, fruit-tree plantations on terraces and various measures to control soil erosion (Pascon and Wusten, 1983). Despite these efforts, the provision of natural resources is still declining, and land degradation is of major political and social concern (Al Karkouri, 2003).

1.2. Stakeholder selection

In MCA, there are no strict rules on whom stakeholder to include (Banville et al., 1998), but it is crucial that all actors who can affect or can be affected by the decision are included (Macharis et al., 2012). In our case, we established a multi-stakeholder platform enclosing people involved in land use management decision in Béni Boufrah. A total of 67 individuals were involved (Appendix 1). They comprise a wide and representative sample of age, gender, education level, socio-professional profile, proximity to the area and dependence on natural resources. We distinguished between three groups of stakeholders: (i) *scientists and managers*, (ii) *collaborators* and (iii) *direct users* (Derak et al., 2016; Table 1). The two latter were considered as local stakeholders. *Scientists and managers* have advanced educational degrees and a relatively high income level. They commonly live outside the area and have large experience in environmental activities such as ecological restoration. They have a significant influence on the decision making process linked to land use planning. *Collaborators* hold secondary and higher educational degrees, and half of them enjoy relatively high income levels. They live in the area and are familiar with environmental activities. They play a relevant role as facilitators for the implementation of socio-development projects. *Direct users* have low to very low education level, and most of them have low incomes. The all live in the area, and few of them have previous experience with environmental activities. They strongly rely on the use of local natural resources.

Our study focuses on the divergence of opinions and interests between and within the three groups of stakeholders. Thus, for each group, we distinguished a number of sub-groups, separated on the basis of socio-demographic profile, professional activity and role in the decision making process. Equilibrated number of individuals per sub-group was also taken into consideration. Accordingly, for s*cientists and managers*, we distinguished two sub-groups: *scientists* and *managers*. For *collaborators*, we differentiated between *authorities and representatives*, *NGOs members*, and *facilitators*. Finally, for *direct users* we distinguished between *farmers*, *members of agricultural cooperatives*, *other users*, and *inhabitants* (Table 1).

1.3. Multi-criteria analysis

1.3.1. Problem structuring and data gathering

The MCA structure included three levels. The first level (criteria) corresponded to five categories of ecosystem services: supporting, regulating, provisioning, cultural services, and biodiversity, as described in MEA (2005), in addition to economical benefits. Hereafter, we consider all six criteria as being categories of ecosystem services. In the second level, each category enclosed a number of ecosystem services (sub-criteria). In total, 17 services were assessed (Table 2). The third level corresponded to five dominant land use options (alternatives) to be compared. We considered three forest uses and two agricultural uses (Figs. 1 and 2). Forest uses included *Tetraclinis articulata* woodlands, *Pinus halepensis* plantations, and shrublands dominated by lavender (*Lavandula dentata* L.) and thyme (*Thymus vulgaris* L.). Agricultural uses included almond tree plantations on cereal crops, and naturalized cactus groves. The MCA consisted on the comparison of the five land use options regarding their contribution to the provision of the 17 ecosystem services. The selection of criteria, sub-criteria and alternatives was based on data availability, our own experience in Béni Boufrah and similar semiarid areas (Derak and Cortina, 2014) and stakeholder recommendations. Thus, we held formal and informal meetings with stakeholders with deep knowledge of the environmental and socio-economic context of the area, who are frequently involved in the design and implementation of local land use strategies. We hence called for the opinion of six experts in hydrology, forestry and sociology and for the advice of governmental officers, environmental organizations and representatives of the local population.

For each land use type, the seventeen ecosystem services were assessed using a set of indicators whose values were established in quantitative and semi quantitative scales. Eight indicators were assessed through direct measurements, seven indicators were deduced from previous reports and studies carried out in the same area, and two indicators were established using global data sets (Table 2). Measured vegetation indicators were vascular plant species richness, number of endemic species, forage supply, and richness of Aromatic and Medicinal Plants (AMP). For each land use type, vegetation measurements were performed on three 20 x 20 plots. In the same fifteen plots, topsoil (0-10 cm) was sampled and analysed in the laboratory to quantify total organic carbon concentration. Aesthetic and traditional values were established on the basis of stakeholder preferences, using five pictures illustrating the five land uses. Game preferences for food and habitat were comparatively assessed for the five land uses according to the opinion of 12 local hunters. Erosion and flood control for the different land uses was deduced from studies of Al Karkouri (2003), Aboulabbes et al. (2005), and Ortiz (2010). Biomass accumulation was estimated from previous studies carried out in Béni Boufrah and similar semiarid areas (Fechtal et al., 1995; Agricultural Technical Centre of Béni Boufrah, 2008; Forest Administration of NE Morocco, 2012). Similarly, water supply was obtained from previous studies (Pascon and Wusten, 1983; Bellot et al., 1999; Al Karkouri, 2003). Food production, employment demand and income generation were based on administrative reports of local forestry and agriculture departments (Agricultural Technical Centre of Béni Boufrah, 2008; Forest Administration of NE Morocco, 2012). Primary production and local climatic regulation were estimated from remote sensing data, NASA MODIS dataset and a Landsat-5 TM image, respectively. Further details on the set of indicators are shown in Appendix 2. In addition to ecosystem service provision, the five land uses were assessed regarding the cost of their installation including all necessary field operations and activities such as enclosures, soil preparation, seeding, planting, etc. (Table 2).

1.3.2. Standardization

Standardization allows criteria to be comparable by transforming their values per alternative into a same numeric scale, which is commonly a dimensionless [0-1] scale. The value 0 corresponds to the least desirable situation and the value 1 to the most desirable one. Standardization procedures are generally classified into two broad categories: linear scale transformation and value function procedures (Demetriou, 2014). The creation of value functions is a difficult task and requires a specially designed interviewing process with decision makers and planners (Beinat, 1997). Thus, for the sake of simplicity, we opted for linear scale transformation. Among the linear methods most widely used in simple additive models are *sum* and *maximum* methods, in which each value is divided by the sum of values and the maximum value, respectively, and *interval* method, which considers both the maximum and the minimum values (Chakraborty and Yeh, 2007). We applied *sum* method because it ensured standardized values of ecosystem service indicators per land use type directly to sum up 1, which led to aggregated scores of the five land use types that summed up 1 (section 1.3.4), being thus comparable to those obtained by direct ranking (section 1.4). With the two other linear methods, an additional task of re-scaling the transformed values between 0 and 1 would be required (Vafaei et al., 2016). For climatic regulation, standardization was based on the inverse of the values, as an increase in Land Surface Temperature was interpreted as a decrease in the contribution to climatic regulation.

1.3.3. Criteria and sub-criteria weighting

To obtain the weights of the six categories and the seventeen services, we performed 15-20 min interviews to 67 stakeholders between November 12th, 2012 and June 9th, 2013. We used a structured questionnaire with close-ended questions. Participants were also given the opportunity to explain and justify their preferences. Additional clarifications and comments were recorded aside, and were used to interpret the results. We succinctly introduced and illustrated the concept of ecosystem services to each stakeholder, using a set of 41 pictures that reflect the most common services in the region.

The weighting questionnaire was divided into two parts. Firstly, we asked stakeholders to rate the six categories of ecosystem services by assigning a value from 1 to 6 to each one, according to its importance in the enhancement of human wellbeing in the area. The value of 6 corresponded to the most important category, and the value of 1, to the least important one. In the second part, we asked stakeholders to compare pairs of services within a given category. Due to the complexity of the 1-9 scale recommended by Saaty (1980) for such comparisons (Kangas, 1994; Strager and Rosenberger, 2006), we adopted a simplified 1-3-5 scale. Value 1 reflected an equal importance between two services, value 3 a moderately higher importance, and value 5 denoted greatly higher importance. One approach to obtain the weight of each service is to calculate its partial weight within the corresponding category, and multiply it by the weight of this category. However, our decisional structure enclosed an uneven number of services by category (2, 3 and 5 services), so such procedure could cause over-estimation of some services and sub-estimation of others. To prevent this flaw, we constructed a 17 x 17 reciprocal matrix which crossed all services together. In addition to the preference values resulting from pairwise comparisons of services within categories (second part of the questionnaire), the new matrix enclosed preferences of services belonging to different categories as a ratio between pairs of values assigned to each category (first part of the questionnaire). The weights of the 17 ecosystem services were then deduced by applying the eigenvalue method, and their sum was equal to 1. The collective weights corresponding to the 67 stakeholders, to each of the three stakeholder groups, and to each of the nine sub-groups were established by calculating the arithmetic mean of the individual weights.

1.3.4. Calculation of aggregated scores

To obtain the overall scores for all land use types according to each stakeholder opinion, standardized indicators values and corresponding weights were aggregated, using a weighted additive method. The sum of the aggregated scores adds up to 1. Overall contribution of a land use type to the provision of ecosystem services was considered proportional to its aggregated score. As for the weighting phase, collective scores were obtained by calculating the arithmetic mean of individual scores.

1.3.5. Sensitivity analysis

Sensitivity analysis was conducted to examine the extent of possible variations in the ranking of the five land use types as a consequence of changes in each of the 17 ecosystem service weights.

1.4. Direct ranking of land uses

In the same interviews and after the weighting phase, we asked each stakeholder to directly rank the five land use types according to their relevance in the area and their contribution to the provision of ecosystem services. By doing so, stakeholders were performing their own MCA, i.e. ranking land use types considering both service values and weights. The obtained scores were rescaled to sum 1 in order to compare them with MCA scores.

1.5. Feed-back workshop

After completing the interviews, we organized a feed-back workshop in Béni Boufrah village (June 11th, 2013). Among 26 participants, 20 persons belonged to our platform with a sufficient representation of the three stakeholder groups. The objectives of the workshop were to share the results of the survey, to discuss them regarding stakeholder needs and aspirations, and to stimulate a constructive debate over the best practices and strategies for natural resource conservation and land use planning.

1.6. Statistical analysis

The collective overall scores of land uses derived from MCA and direct ranking summed 1 and were inter-dependent. Non-parametric Friedman test followed by Wilcoxon post-hoc test was therefore used to check for significant differences between averaged scores of land uses for the 67 stakeholders.

2. Results

The provision of ecosystem services differed widely between the different land use types assessed (Table 2). For forest land uses, Tetraclinis woodlands enhanced the majority of services, especially soil fertility, primary production, erosion and flood control, and water supply. In contrast, this land use supplied no food and scarce forage, and generated the lowest incomes (130 US$ ha^{-1} $year^{-1}$). Pine afforestation had both positive and negative effects on the provision of ecosystem services. It had a positive effect on primary production, biomass accumulation, and hydrological and local climatic regulation, and created the highest employment demand, three to six times higher than other land uses did. However, pine plantations supplied no food or forage, showed low aesthetic and traditional values, and had a negative effect on game abundance and biodiversity (plant richness, endemism). Shrublands provided low to medium levels of most services, except for AMP richness and game abundance, which were higher than in other land uses. Among agricultural land uses, Cereal-almond crops excelled over other land uses in terms of food and forage supply, traditional value and income generation. However, they showed the lowest levels of soil fertility and their contribution to erosion and flood control was meagre. Cactus groves provided high levels of food, had a relevant traditional use, and strongly contributed to species richness (47 species). Conversely, their aesthetic value and their contribution to local employment were low. In terms of establishment costs, cactus showed the lowest costs (200 US$ ha^{-1} $year^{-1}$) and crops the highest costs (800 US$ ha^{-1} $year^{-1}$) of the five land uses studied.

According to stakeholder opinions, priorities in Béni Boufrah were linked to regulating, supporting and provisioning services (Table 3). More specifically, the most important services, in decreasing order, were water supply, erosion and flood control, soil fertility and food provision. Biodiversity, economical benefits and cultural services were the least valued by stakeholders. We obtained similar patterns when we analysed the three stakeholder groups and the nine sub-groups separately. Yet, we observed some remarkable differences. As illustrated in Table 3, local stakeholders (*collaborators* and *users*) assigned a slightly higher importance to soil fertility and food supply in comparison to s*cientists and managers.* Conversely, the three services linked to biodiversity (specific richness, endemic richness and game abundance) were highly valued by s*cientists and managers*, but not by local stakeholders. The sub-group level analysis showed that undervaluation of services linked to biodiversity was not observed for all local stakeholder sub-groups but only for *authorities and representatives*, *members of cooperatives* and *other users* (Appendix 3).

The MCA, based on the opinion of the 67 stakeholders, led to an integrated classification of the five land uses, according to their contribution to the provision of ecosystem services. Tetraclinis woodlands showed the highest contribution, whereas Shrublands showed the lowest one. Cactus groves, Cereal-almond crops and Afforestation occupied intermediate positions (Fig. 3). We obtained a similar ranking when we analysed separately preferences of the three groups of stakeholders (X axis in Fig. 5) and the corresponding nine sub-groups (X axis in Fig. 6). Sensitivity analysis showed that MCA results responded to changes in stakeholder weights of four ecosystem services (Fig. 4). For instance, an increase in the weight of food supply from 0.070 to 0.122 substantially changed MCA results. In this case, cactus was the most suitable option, followed by Cereal-almond crops and Tetraclinis woodlands. Similarly, an increase in the weight of forage production (0.053 to 0.119) and income generation (0.045 to 0.150) increased the preference for crops, which ranked first. Afforestation was the most preferable use when employment weight increased threefold, from 0.044 to 0.130.

As found for the MCA, direct ranking confirmed that the set of preferred land uses corresponded to Tetraclinis woodlands, Cereal-almond crops and cactus groves. In contrast, separate analysis for the three different stakeholder groups led to major differences (Fig. 5). While MCA showed that Tetraclinis was the most suitable land use for the three groups of stakeholders (right side of the X axis in Fig. 5), direct ranking revealed that the most desirable land uses were Tetraclinis and crops for s*cientists and managers*, and crops and cactus for *users* and *collaborators* (upper side of the Y axis). Furthermore, MCA showed that, for the three groups, Shrublands was the least suitable land use type, whereas direct ranking identified Afforestation as the least preferable land use type.

The analysis of the direct ranking results at the sub-group level revealed that differences of opinion exist also within each of the three groups of stakeholders. Indeed, while *managers* considered Tetraclinis woodlands and Cereal-almond crops as the most suitable land uses, *scientists* assigned a relevant high value to Crops and a low value to Tetraclinis (Fig. 6a). In comparison to the sub-group of *authority and representatives* and that of *facilitators*, who considered both Crops and Cactus as the most preferable land uses, *NGO members* considered Cactus as distinctly the most preferable land use (Fig. 6b). Among the four *direct user* sub-groups, *farmers* were distinguished by clearly focusing their first choice on Crops (Fig. 6c). The last position obtained by Afforestation was confirmed at the sub-group level, except for *other users* and *inhabitants* who instead considered Shrublands at the least desirable land use.

During the workshop, discussions showed a higher level of agreement with results of direct ranking evaluation than MCA outputs. In fact, all participants recognized the multitude of services provided by Tetraclinis woodlands and manifested their support to any effort to protect and restore them. Local stakeholders insisted on the absolute priority that should be given to interventions involving crops and cactus.

3. Discussion

3.1. Ecosystem services provided by land uses

From an empirical perspective, the data matrix presented in Table 2 provides an overview of the effects of land use on the assessed ecosystem services. Many services were similarly provided by more than one land use, but others were only guaranteed by a given land use. Furthermore, we observed substantial differences in the provision of some services between and within the two main categories of uses, i.e. forest and agricultural uses.

Of the forest uses, Tetraclinis woodlands were characterized by their high contribution to the enhancement of the majority of ecosystem services, except for food and forage supply and income generation. The importance of Tetraclinis forests in providing many ecological, socioeconomic and cultural goods and services has been emphasized in Béni Boufrah (Pascon and Wusten, 1983) likewise in other semiarid Moroccan areas (Khotbi, 2004). With a less prominent role, Pine afforestation had positive effects on hydrological and local climatic regulation, primary production, and employment supply, compared to other land uses, which is common to other *Pinus halepensis* plantations in semiarid Mediterranean areas (Pastor, 1995; Tunisian Forest Inventory, 1995; Derak and Cortina, 2014). Yet, our results confirmed previous findings about null to negative effect of pine plantation on ecosystem services such as water availability (Bellot et al., 1999), plant richness (Gómez-Aparicio et al., 2009), and game abundance (Belda et al., 2011). In Béni Boufrah as well as in similar valleys of the Rif, shrublands represent marginal and degraded lands (Avril, 1966) that contribute weakly to the provision of most ecosystem services. However, Shrublands showed high AMP potential, which may contribute to the economies of households and local cooperatives.

Of the two agricultural uses analysed, Cereal-almond crops played a relevant role in food and forage supply, traditional value and income generation, which confirms their importance as an economic and alimentary asset for local populations (Jungerius et al., 1985). However, Crops showed three major limitations, as their value to maintain soil fertility and control erosion and flooding was comparatively low. This may be related to the abandonment of traditional conservation agricultural techniques in Béni Boufrah (Jungerius et al., 1985; Al Karkouri et al., 2006), as in the Rif region (Sabir et al., 2004; Gauché, 2006). As compared to

Crops, Cactus groves provided higher levels of supporting and regulating services, which confirms their ecological role, particularly in controlling erosion and improving soil fertility (Nefzaoui and El Mourid, 2010). The high value of specific richness found under cactus cover has been reported elsewhere (Neffar et al., 2013), and may be related to their relatively high cover, their structural complexity, and the risk of thorns (as the spiny variety is widespread). Cactus complex structures create contrasted microhabitats, and shelter plants from direct radiation and herbivores. Cactus groves in Béni Boufrah also hold the highest levels of nutritional value and the second highest amount of economic income, which confirms its increasing nutritive and economic role in semiarid North African areas (Mulas et al., 2012).

3.2. Stakeholders preferences towards ecosystem services

The diversity of ecosystem services provided by different land uses types illustrates the complexity of management decisions regarding land use allocation. Focusing on the most relevant priorities in the area may be a way to meet such challenge. According to the opinion of the 67 stakeholders, the main priorities in Béni Boufrah were related to hydrological regulation, support of soil fertility and provision of water and food. That reflects people concerns over erosion and flooding, as they threaten human lives, infrastructures and agricultural and pastoral productivity in Béni Boufrah and other areas of the Central Rif (El Khattabi, 2001; Al Karkouri, 2003; Aboulabbes et al., 2005; Laouina, 2010).

Our results are in agreement with previous studies in semiarid areas of southern and south-eastern Spain in which stakeholders attached a high priority to regulating services and soil formation (Castro et al., 2011; Martín-López et al., 2012; Derak and Cortina, 2014). Similarities are not surprising, given the constraints posed by biophysical conditions. However, stakeholder concerns on local hydrological and agricultural issues are likely to be more pressing in Morocco than in Spain. Semiarid areas in the former country face high human pressure, and forest conversion to agricultural land is ongoing (Al Karkouri et al., 2006), whereas in semiarid areas in the northern Mediterranean agricultural abandonment prevails (Rodríguez-Aizpeolea and Lasanta-Martínez, 1992).

Preferences in Béni Boufrah were remarkably similar for the three groups and the nine sub-groups of stakeholders. Exceptions were restricted to small differences between *scientists and managers*, on the one hand, and local stakeholders (*direct users* and *collaborators*), on the other. Thus, in comparison to local stakeholders (more precisely *authorities and representatives*, *members of cooperatives* and *other users*), *scientists and managers* showed higher awareness on the role of biodiversity for human well-being, but limited appreciation for agricultural production. Regarding the precision of the emitted judgments, Derak et al. (2016) found that the accuracy of pair-wise ecosystem service comparisons was similar for the three stakeholder groups. These results support the idea that the judgment of *scientists and managers* should not be considered as more credible than that of *local stakeholders* (Noble, 2004), and that skills, knowledge and experience of all groups may be complementary for assessing environmental priorities (González et al., 2009; Elbroch et al., 2011).

3.3. MCA of land uses

By using a combination of empirical data and social perception, we identified Tetraclinis woodlands as the most suitable land use in Béni Boufrah valley. This was mainly due to its relatively high contribution to the provision of ecosystem services that were highly valued by stakeholders, i.e. soil fertility, erosion and flood control and water supply. Our results are in agreement with previous studies which considered forests as one of the most suitable land use alternatives in the Central Rif. This reflects their ability to provide multiple ecological functions, stimulating local economy, and contributing to sustain local populations (Grovel, 1996). Pine afforestation was less suitable than Tetraclinis, because of its low to negative effect on valuable services such as food and water supply. Its positive effect on local climatic regulation and biomass productivity barely contributed to its integrated value, as these services were less appreciated by the population. Still, Pine afforestation was preferable to Shrublands. This result is in agreement with the study of Derak and Cortina (2014) who showed that Pine afforestation provided higher levels of ecosystem services than shrublands, grasslands and abandoned agricultural fields in a semiarid area of South-eastern Spain. The relatively high score attained by Cactus groves was somewhat surprising. Several ecosystem services contributed to this, including alimentary and economic value, soil fertility and species richness. In contrast, the positive effect of Cereal-almond crops on the provision of food and economic revenues was offset by their poor contribution to supporting and regulating services.

The aim of MCA is not to bring a unique solution, but to allow decision makers to visualise their decision under different circumstances, and in conformity with their conception of the decisional problem and their initial goals (Roy, 1985; Malczewski, 1999). In Béni Boufrah, ranking of different land use types may vary, depending on socio-cultural, institutional and political conditions. This may lead to changes in priorities. As shown in sensitivity analyses, if stakeholders concern on food resources was higher, the preferred land use type would be Cactus groves, instead of Tetraclinis woodlands. Similarly, if their dominant concerns were the increase in forage production and the generation of economic income, Cereal-almond crops would take the first place in the ranking. Following the same reasoning, if stakeholders would strongly prioritise employment opportunities, Pine afforestation would be the most suitable option for this valley.

3.4. MCA vs. direct ranking of land uses

The aggregated scores computed by MCA elicited significant differences between the various stakeholder collectives. Yet, the magnitude of these differences was lower than those found when direct choices of the different collectives were evaluated. This may be a consequence of the heterogeneity of their real needs and interests (Davies et al., 2003). Thus, MCA classification of the five land uses was similar for the three groups and the nine sub-groups of stakeholders, whereas direct ranking revealed more differences between and within stakeholder groups, leading to two broad sets of opinion, one formed by *managers* and the other by *scientists* and local stakeholders (*collaborators* and *users*).

By identifying Tetraclinis woodlands as the most preferable option, at a similar level for Crops, *managers* were probably considering natural forests as a solution for the most critical problems in the area, i.e. soil fertility, erosion and flood control, and water supply. Their choice is compatible with MCA outcomes, which simultaneously considered all services under assessment. *Scientists* did not show the same position as they considered Tetraclinis of a lower importance and Crops as the best alternative for the area. Despite that local stakeholder priorities, in terms of ecosystem services, were close to those of *managers*, direct choice did not strictly translate these preferences, as they considered crops and cactus as more desirable than Tetraclinis. This probably reflects their concern on daily needs, and their interest on instant benefits. In fact, in such participatory exercises, local population often focuses on personal interests than on issues of broad interest (Van den Hove, 2006).

Our results suggest that, *scientists* and local stakeholders attach higher importance to a reduced set of services, such as food and forage supply and income generation, when using direct ranking. This is in agreement with simulations obtained in the sensitivity analysis which revealed that when hypothetical priorities are highly attached to one of these three services, Cereal-almond crops and Cactus become the most desirable land use types. These direct choices were confirmed in the discussions maintained during the feed-back workshop. There, all stakeholders recognized the eminent role of Tetraclinis woodlands to enhance most ecosystem services, and thus to improve human well-being in the area, but the first choice of local stakeholder was inclined towards crops and cactus.

Concerning Pine afforestation, while MCA, performed for the three groups and the nine sub-groups of stakeholders, agreed in the intermediate role of this land use type as an ecosystem service provider, direct ranking revealed that most stakeholders were not convinced of its role. Thus, Pine afforestation was considered the least preferable option by various collectives of stakeholders (except for *other users* and *inhabitants)*, together with Shrublands.

3.5. Application in rehabilitation and restoration strategies

Land degradation in the Central Rif requires urgent intervention in the form of land conservation and restoration measures (Grovel, 1996). In comparison to *Pinus halepensis plantations*, interventions based on *Tetraclinis articulata* may provide more ecological benefits such as a significant equilibrium with soil and flora, a high pastoral value, and a low sensitivity to forest fires (Benabid, 1983; Ortiz, 2010). Our results confirm these observations, as they showed that Tetraclinis forest was preferred over Pinus afforestation regarding the provision of ecosystem services and social acceptance. Recent efforts to promote Tetraclinis regeneration by the Forest Service in Al Hoceima province, and Moroccan High Commissary for Waters and Forests strategy to prioritize autochthonous species, confirm the increasing awareness on the role of this species as a key factor for the enhancement of nature conditions and human wellbeing in the area.

Previous studies suggest that planting cactus is a simple, cheap and efficient practice to mitigate land degradation in semi-arid areas of North Africa (Nefzaoui and El Mourid, 2010; Mulas et al., 2012). Our results confirm these observations. Cactus groves was the cheapest alternative, they enhanced most ecosystem services, and were well accepted by most stakeholders. Thus, our results support recent efforts from the Agricultural Service in Béni Boufrah to plant cactus over 500 ha of marginalized and abandoned areas with the aim of improving ecological and socioeconomic conditions. Yet, being an exotic species with a large potential for naturalisation (Ibn Tattou et al., 2014), cactus should be used with extreme caution, taking the necessary measures to control its expansion and avoid undesirable landscape transformations.

3.6. Implication for land use planning

Our approach was based on the intertwined relationship between the biophysical world and human judgments, as it combined empirical data and social preferences on ecosystem services. Land use classifications based on MCA and direct ranking improved our understanding on stakeholder preferences. MCA simultaneously integrated the seventeen ecosystem services and showed a convergence between stakeholders regarding the most and least suitable land use types. Direct ranking, based on a more "subjective" integration of the notion of ecosystem services in land use assessment, allowed depicting divergence of opinions and interests between stakeholder groups and also between sub-groups of hypothetically homogenous stakeholder groups, such as the case of *scientists* and *managers*.

These results must now be examined and validated together with stakeholders, contributing to the development of a new management framework based on constructive dialogue, reciprocal learning and deliberative democracy (Dodgson et al., 2001; Munda, 2004). With this aim, we shared our results with stakeholders during a feed-back workshop, and collected their comments, critics and suggestions. We also discussed the most appropriate interventions to enhance socioeconomic conditions in the area, and potential hurdles for their implementation. Such integration of MCA and participatory processes may stimulate reflection among stakeholders, strengthen their ownership feeling and increase the flexibility and efficiency of administrative decisions (Stirling, 2006; Spangenberg et al., 2015). However, it is worthwhile to note that stakeholder willingness to participate was higher for the individual interviews (67 participants) than for the collective meeting (26 participants). This was mainly due to personal impediments, but also to conflicting relationship between some categories of stakeholders, especially the local population, and the Forest Administration.

Further efforts are needed to motivate stakeholders to accept and interact with each other, and actively participate in collective events.

Early stakeholder involvement in development projects in rural areas of North Africa increase the likelihood of successful implementation (Melhaoui, 2002; Mulas et al., 2012). Furthermore, in these areas, characterized by high rates of poverty, illiteracy and dependence on natural resources, empirical evidence shows that raising awareness is crucial to encourage stakeholder engagement. In this context, the use of practical and clear definitions of ecosystem services, adapted to local language, knowledge and values, is crucial for stakeholders to understand their implications on everyday life (McKenzie et al., 2014). Local stakeholders were aware of the role of natural forests as sources of vital ecosystem services. Yet, they were largely concerned by a few sets of services, so that their choices were more inclined towards agricultural land uses. From a practical perspective, we strongly recommend that efforts by the Forest and Agricultural Administrations should be coordinated, and upscaled to focus on landscapes, rather than specific ecosystems. By doing so, interventions may be perceived by different groups of stakeholders as simultaneously targeting different ecosystem services, and responding to scientific and technical evidence, as well as to social needs and aspirations.

In our study, we compared collective opinions and explored the averaged value obtained for pre-established stakeholder groups. A complementary individual analysis can also be launched to establish the relation between stakeholder preferences and his/her socio-cultural and economic condition. Such individual analysis will enhance our understanding of stakeholder values and perceptions towards ecosystem services management and land use planning, taking into account the wide diversity of individuals (García-Llorente et al., 2012; Martín-López et al., 2012).

In the beginning of the MCA, we asked a number of potential stakeholders to check and complete a pre-established list of criteria (ecosystem services) and alternatives (land uses). Time and resources permitting, it would be preferable to let all participants to brainstorm and discuss the list of criteria and alternatives to be included in the analysis through individual interviews or participatory workshops. That would ensure a better integration of stakeholder knowledge and values (Davies et al., 2003; Spangenberg et al., 2015), improve their understanding of the process and its results, and encourage their engagement.

Stakeholders utilizing ecosystems tend to behave for their own interest rather than for the interest of the community. More research is needed to integrate behavioural and psychological science in MCA and ecosystem service-based approaches (Stagl, 2006; Primmer et al., 2015). Such studies would be helpful to better understand why stakeholders choose land use options that do not necessarily match their critical problems, and which procedural mechanisms are required to measure the distance between stakeholder real choices and the expected numerical calculations resulting from MCA.

Conclusion

In developing countries, land use planning decisions are often made by administrative authorities, without deep and active engagement of a wide range of social actors. Stakeholder involvement and the combination of Multi-criteria Analysis and direct ranking improved the assessment process in Béni Boufrah valley, and allowed the identification of the most suitable land use options matching ecosystem services enhancement and stakeholder aspirations. A small set of land uses, particularly Tetraclinis woodlands, Cactus groves and Cereal-almond crops, emerged as suitable targets for mitigating land degradation and improving local socioeconomic conditions. Our approach allows the identification of desired land use alternatives, while encouraging constructive debate and reciprocal learning. It also provides complementary information that may help decision makers to understand the underlying causes of stakeholder preferences and facilitate consensus building. Further research is needed to explore the reasons for possible differences between MCA outputs and direct stakeholder choices on land use options.

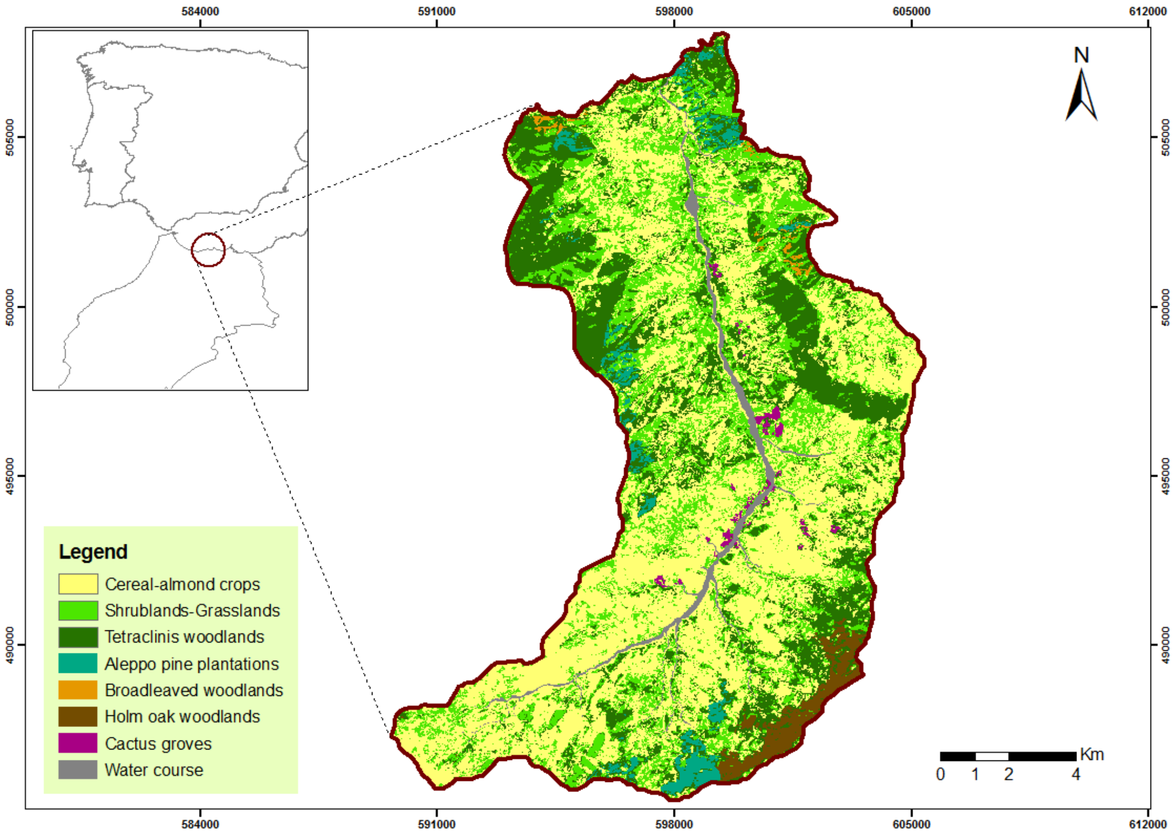


Figure 1.Location and land use distribution in Béni Boufrah Valley, Morocco.

Table 1.Composition of the stakeholder platform established to evaluate ecosystem services in Béni Boufrah (N Morocco).

Groups	Number of persons per group	Sub-group	Number of persons per sub-group	Stakeholder category	Number of persons per stakeholder category
Scientists and managers	19	Scientists	8	Researchers, University Faculty	8
		Managers	11	Forest Administration	6
				Agricultural Administration	4
				Hydrological department	1
Collaborators	20	Authority and representatives	5	Local authority	2
				Municipal representatives	3
		NGO members	6	NGOs members	6
		Facilitators	9	Touristic facilitators	2
				Primary school professors	1
				Local developers	2
				Other functionaries	4
Direct users	28	Farmers	6	Farmers	6
		Members of cooperatives	8	Members of cooperatives	8
		Other users	7	Fishermen	5
				Hunters	1
				Lumberjacks	1
		Inhabitants	7	Inhabitants	7
Total	**67**		**67**		**67**

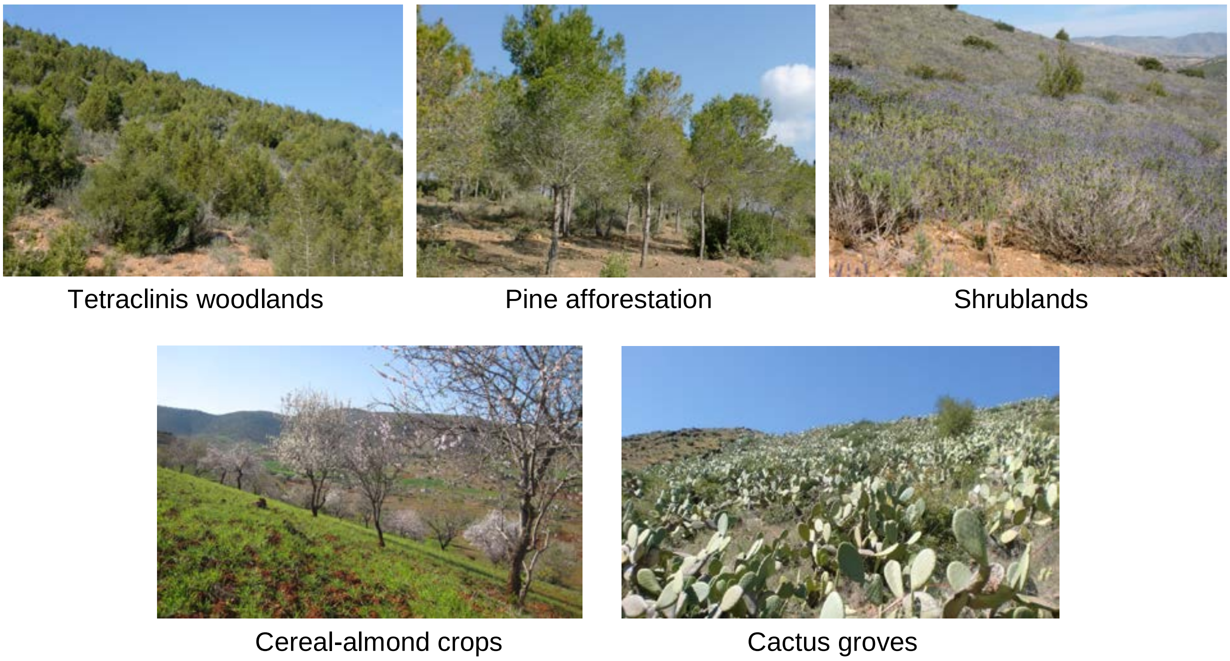


Figure 2. Panoramic views of the five assessed land uses in Béni Boufrah catchment.

Table 2.Value of ecosystem services and their indicators for different land uses types in Béni Boufrah catchment. Standard error is shown when available. Data source and establishment costs are also shown. AMP: Aromatic and Medicinal Plants. See Appendix 2 for further details on the methodology.

			Land use type					
Category	Ecosystem service	Indicator	Tetraclinis Woodlands	Pine Afforestation	Shrublands	Cereal-almond Crop	Cactus grove	Data source
Supporting services	Soil fertility	Organic soil carbon in soil surface (%)	4.1±1.5	3.2±1.4	3.5±0.2	1.5±0.3	3.1±0.7	Sampled
	Primary production	Net Primary Production (g C m^{-2} $year^{-1}$)	620±20	615±52	370±20	360±9	205±32	NASA MODIS dataset
Regulating services	Erosion control	Contribution to soil control	+++	++	-	-	+	Previous studies
	Flood regulation	Contribution to flood control	+++	++	-	-	+	Previous studies
	Local climate regulation	Land Surface Temperature (°C)	32.2±0.2	31.5±0.5	33.7±0.2	34.3±0.1	33.8±1.1	Landsat-5 TM data set
Provisioning services	Biomass accumulation	Biomass accumulation (kg ha^{-1})	7850	10650	1710	2700	6000	Previous studies
	Forage supply	Pastoral value (%)	1	0	4	10	2	Sampled
	Food supply	Nutritive value (10^6 Kcal ha^{-1})	0.0	0.0	0.0	2.5	2.9	Administrative reports
	AMP richness	AMP cover (%)	25	14	46	8	14	Sampled
	Water supply	Contribution to water supply	++	+	+	+	+	Previous studies
Cultural services	Aesthetic value	Aesthetic value (score)	3.9±0.1	2.2±0.1	3.4±0.1	3.6±0.1	1.9±0.1	Sampled
	Traditional value	Traditional value (score)	3.2±0.2	1.4±0.1	2.8±0.9	3.8±0.1	3.8±0.1	Sampled
Biodiversity	Specific richness	Number of plant species	21	19	33	30	47	Sampled
	Endemism	Number of endemic plant species	1	0	2	2	3	Sampled
	Game abundance	Small and big game preferences for foods and habitats (score)	3.6±0.4	1.7±0.3	3.6±0.4	2.9±0.4	3.2±0.4	Sampled
Economical benefits	Employment demand	Annual employment demand (days ha^{-1} $year^{-1}$)	20	75	15	30	10	Administrative reports
	Income generation	Economic income from marketable products (US$ ha^{-1} $year^{-1}$)	130	400	375	615	420	Administrative reports
Cost	---	Establishment cost (US$ ha^{-1} $year^{-1}$)	600	500	300	800	200	Administrative data

Table 3.Ecosystem services weights derived from the preferences of the 67 stakeholders, and each of the three stakeholder groups. Weights are ranked following stakeholder preferences. Differences in ecosystem services weights between the three groups of stakeholders are highlighted in bold. SS: supporting services, RS: regulating services, PS: provisioning services, CS: cultural services, B: biodiversity, and EB: economical benefits.

Ecosystem service	All stakeholders	Stakeholder group		
		Scientists and managers	*Collaborators*	*Direct users*
Water supply (PS)	0,089	0,084	0,088	0,092
Erosion protection (RS)	0,086	0,085	0,090	0,083
Flood protection (RS)	0,084	0,080	0,085	0,086
Soil fertility (SS)	0,072	**0,064**	**0,071**	**0,077**
Food provision (PS)	0,070	**0,062**	**0,073**	**0,074**
Local climate regulation (RS)	0,068	0,065	0,069	0,070
Primary production (SS)	0,067	0,064	0,064	0,070
Biomass production (PS)	0,055	0,054	0,055	0,057
Forage supply (PS)	0,053	0,053	0,054	0,053
AMP richness (PS)	0,053	0,057	0,049	0,052
Specific richness (B)	0,052	**0,062**	**0,050**	**0,047**
Incomes generation (EB)	0,045	0,048	0,043	0,044
Game abundance (B)	0,045	**0,053**	**0,042**	**0,042**
Employment supply (EB)	0,044	0,043	0,040	0,048
Endemism (B)	0,044	**0,053**	**0,042**	**0,038**
Traditional value (CS)	0,039	0,037	0,044	0,035
Aesthetic value (CS)	0,036	0,036	0,041	0,032

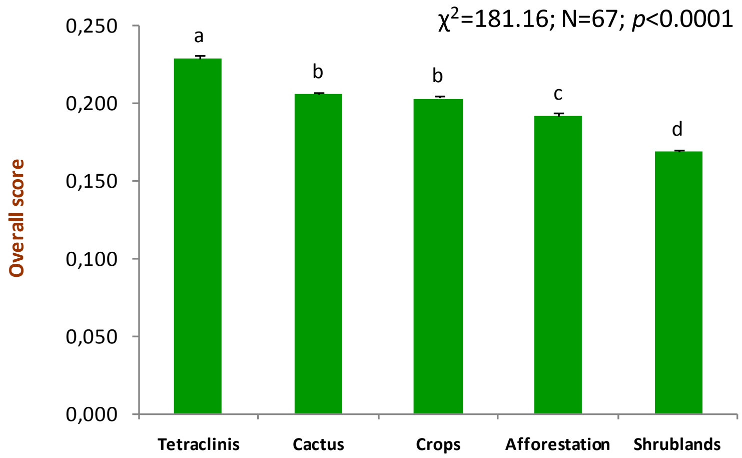
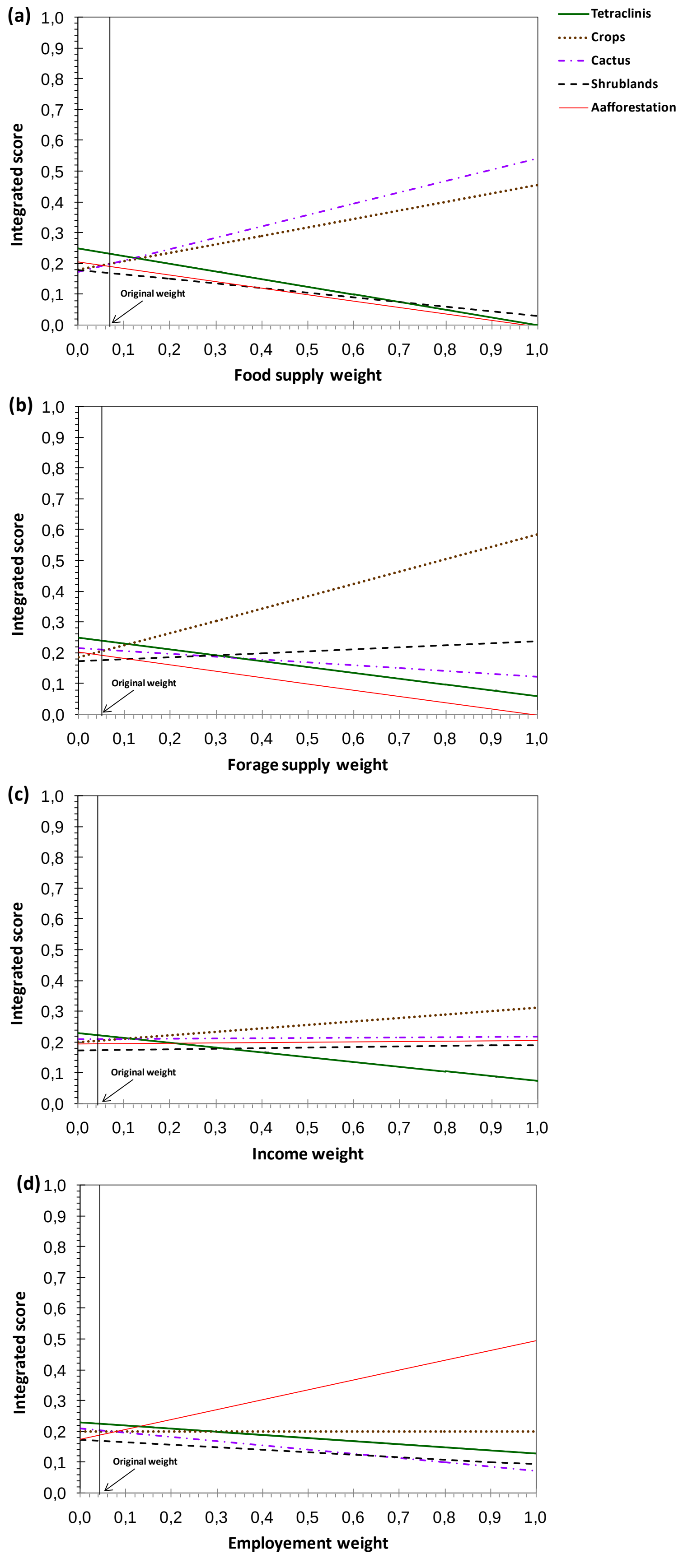
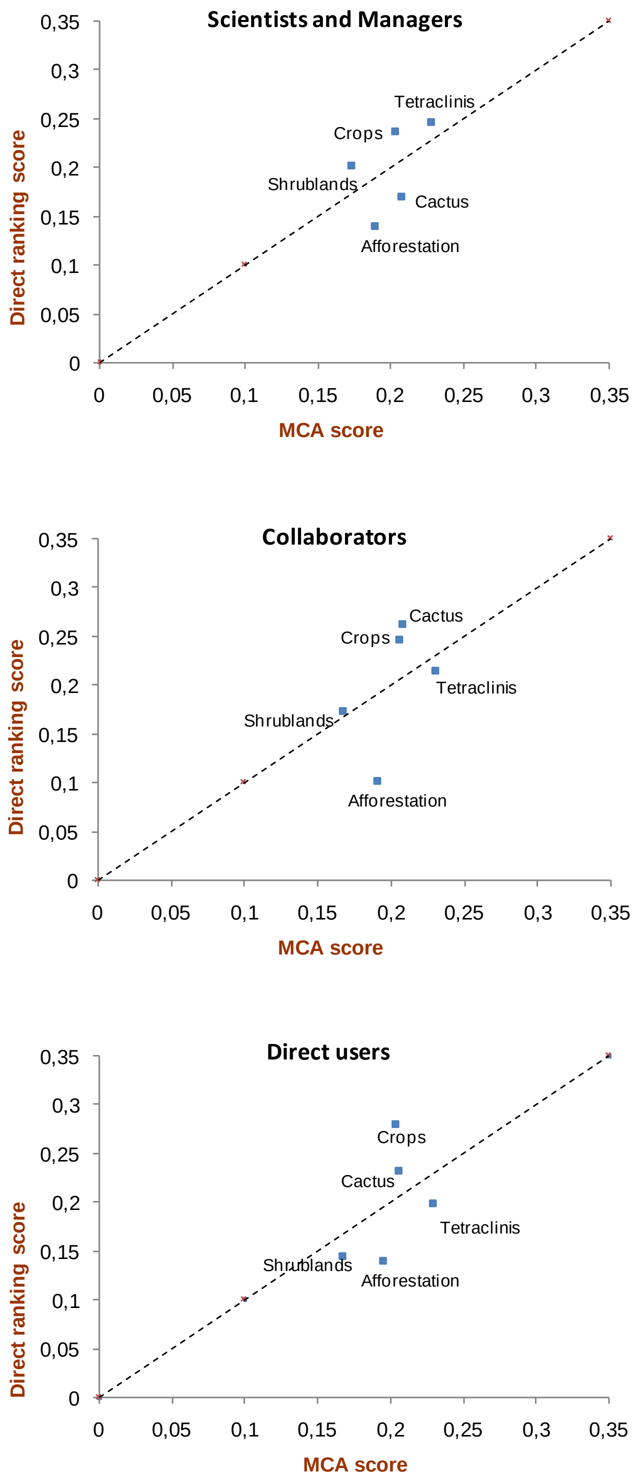


Figure 3.Ranking of the five land use types under assessment, regarding their overall contribution to the provision of ecosystem services in Béni Boufrah catchment. The Y axis shows the overall scores obtained by means of a MCA combining empirical data and stakeholder preferences. Results of the non-parametric Friedman tests are shown. Different letters indicate significant difference between land use types (Wilcoxon Post hoc test, p<0.05).



593 Figure 4.Sensitivity analysis showing potential shifts in land use type ranking with changes in the
594 weights of (a) food supply, (b) forage supply, (c) income generation and (d) employment demand.



595 Figure 5. Relation between overall scores of the five land use types assessed by MCA and direct
596 ranking for each of the three stakeholder groups in the Béni Boufrah valley.

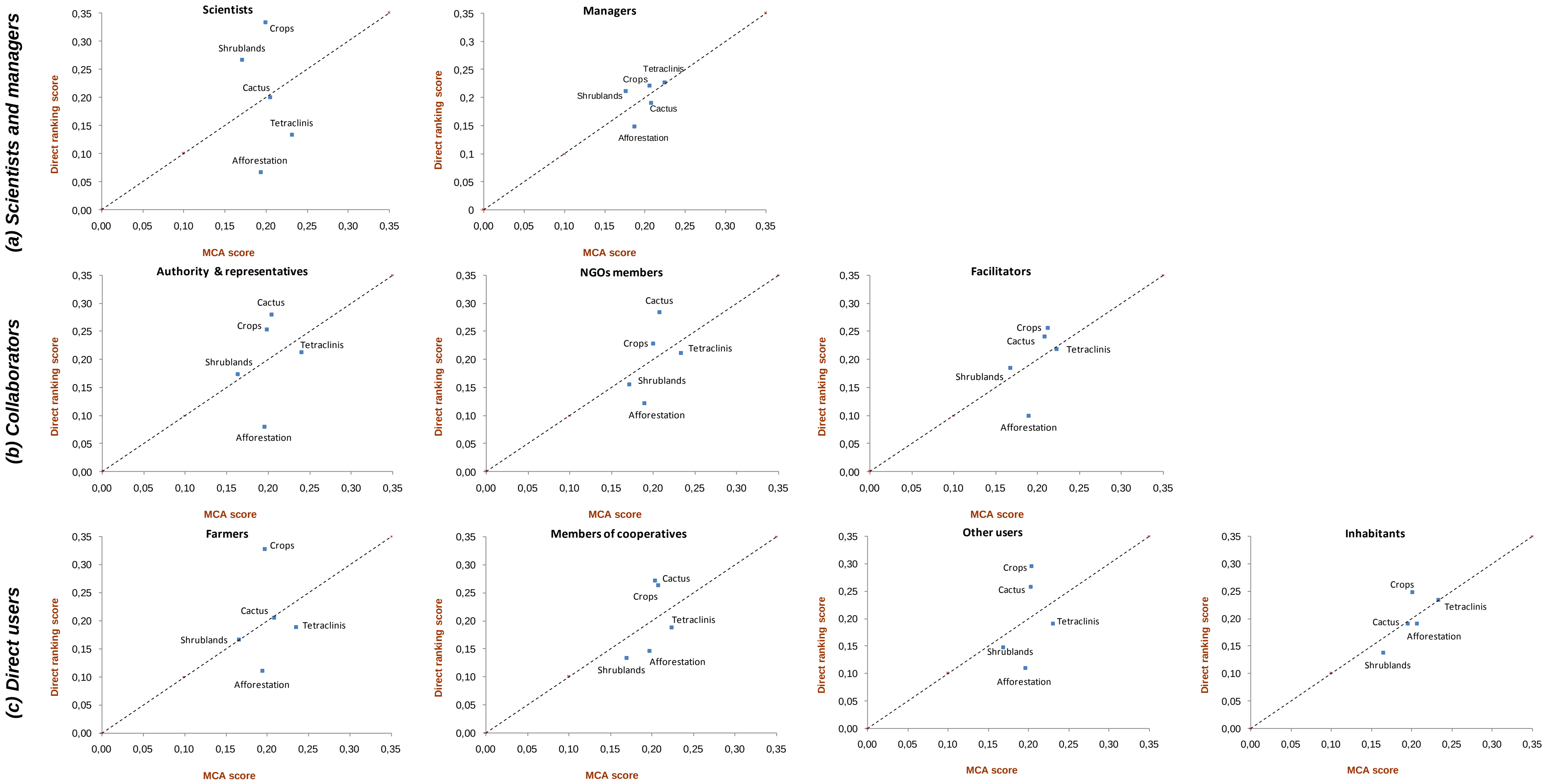


Figure 6. Relation between overall scores of the five land use types assessed by MCA (X axis) and direct ranking (Y axis) for each of the nine stakeholder sub-groups in the Béni Boufrah valley.

Appendix 1. Main socio-demographic characteristics of the 67 participants belonging to the three groups of stakeholders. W: Woman; M: Man.

N°	Age (year)	Gender	Occupation	Organization	Residence/Location	Stakeholder group
1	46	W	Cooperative member	Ferdaouss cooperative	Agni	Direct users
2	25	W	Cooperative member	Ferdaouss cooperative	Béni Boufrah	Direct users
3	32	W	Cooperative member	Ferdaouss cooperative	Béni Boufrah	Direct users
4	25	W	Cooperative member	Ferdaouss cooperative	Béni Boufrah	Direct users
5	40	W	Cooperative member	Sobarif cooperative	Béni Boufrah	Direct users
6	52	M	Primary school teacher	Béni Boufrah primary school	Béni Boufrah	Collaborators
7	60	M	Seller	***	Béni Boufrah	Direct users
8	58	M	Seller	***	Agni	Direct users
9	43	M	Country house manager	***	Béni Boufrah	Collaborators
10	39	M	Development Agent	Social Development Agency	Rouadi	Collaborators
11	33	M	Forest engineer	Forest Management Office	Al Hoceima	Scientists & Managers
12	29	M	Forest engineer	Forest Administration	Al Hoceima	Scientists & Managers
13	67	M	Fisherman	Cala Iris fishermen cooperative	Badès	Direct users
14	51	M	Fisherman	Cala Iris fishermen cooperative	Jnanate	Direct users
15	60	M	Public functionary	Agricultural nursery	Béni Boufrah	Collaborators
16	53	M	Fisherman	***	Jnanate	Direct users
17	29	W	Cooperative member	Nouar Rif cooperative	Kobià	Direct users
18	39	W	Cooperative member	Nouar Rif cooperative	Jnanate	Direct users
19	40	W	Cooperative member	Nouar Rif cooperative	Izlouguen	Direct users
20	65	M	Tourist guide	***	Tazlda	Collaborators
21	54	M	Public functionary	Local municipality	Béni Boufrah	Collaborators
22	43	M	Public functionary	Youth house	Béni Boufrah	Direct users
23	48	M	Forest technician	Local forest Administration	Béni Boufrah	Scientists & Managers
24	53	M	Public functionary	Forest Management Office	Al Hoceima	Direct users
25	56	M	Agricultural engineer	Agricultural Technical Center	Béni Boufrah	Scientists & Managers
26	50	M	Agricultural engineer	Agricultural Administration	Al Hoceima	Scientists & Managers
27	28	W	NGO member	Badès association	Al Hoceima	Collaborators
28	45	M	NGO member	Badès association	Al Hoceima	Collaborators
29	49	M	NGO member	RODPAL network	Al Hoceima	Collaborators
30	28	M	Tourist guide	***	Al Hoceima	Collaborators
31	61	M	Hunter	Pigeon hunter association	Al Hoceima	Collaborators
32	50	M	Forest engineer	Forest Research Center	Rabat	Scientists & Managers
33	49	M	Researcher	Forest Research Center	Rabat	Scientists & Managers
34	65	M	University professor	National Forest School	Salé	Scientists & Managers
35	38	M	Forest engineer	Forest Research Center	Rabat	Scientists & Managers
36	28	M	Forest engineer	Forest Management Office	Al Hoceima	Scientists & Managers
37	49	M	Forest engineer	Forest Management Office	Al Hoceima	Scientists & Managers
38	55	M	Forest technician	Local forest Administration	Béni Boufrah	Scientists & Managers
39	47	M	NGO member	RODPAL network	Al Hoceima	Collaborators
40	42	W	NGO member	MPDL association	Al Hoceima	Collaborators
41	44	W	NGO member	Snada association	Al Hoceima	Collaborators
42	27	M	Agricultural engineer	Agricultural Administration	Al Hoceima	Scientists & Managers
43	42	M	Engineer in Hydraulic	Hydraulic Agency of Loukkos	Al Hoceima	Scientists & Managers
44	59	M	University professor	Mohamed V University	Rabat	Scientists & Managers
45	54	M	University professor	Abdelmalek Essaàdi University	Tétouan	Scientists & Managers
46	29	W	PhD student	Abdelmalek Essaàdi University	Béni Boufrah	Scientists & Managers
47	53	M	Veterinary technician	Local Agricultural Administration	Béni Boufrah	Collaborators
48	60	M	Public functionary	Local authority office	Béni Boufrah	Direct users
49	34	W	Legal Assistant	Al Hoceima court	Al Hoceima	Direct users
50	44	M	Development Agent	Training Center	Béni Boufrah	Collaborators
51	49	M	Fisherman	***	Jnanate	Direct users
52	48	M	Fisherman	***	Cala Iris	Direct users
53	45	M	Hunter	Amane hunter association	Agni	Direct users
54	34	M	Lumberjack	***	Targuist	Direct users
55	49	M	Municipal representative	Local municipality	Torres	Collaborators
56	50	M	Farmer	***	Torres	Direct users

57	58	M	Farmer	***	Agni	Direct users
58	72	M	Farmer	***	Agni	Direct users
59	42	M	Public functionary	Local municipality	Agni	Collaborators
60	47	M	Farmer	***	Agni	Direct users
61	62	M	Farmer	***	Ibayehtine	Direct users
62	59	M	Cafe proprietary	***	Béni Boufrah	Direct users
63	57	M	Public functionary	Local authority office	Béni Boufrah	Collaborators
64	39	M	Farmer	***	Idghirene	Direct users
65	40	W	University professor	High Normative School	Al Hoceima	Scientists & Managers
66	58	M	Public functionary	Local authority office	Béni Boufrah	Collaborators
67	53	M	Agricultural technician	Agricultural Technical Center	Béni Boufrah	Scientists & Managers

Appendix 2. Detailed description of the methods used to estimate ecosystem services.

Soil fertility

For each land use type, we established three 20 x 20 m plots. We sampled topsoil (0-10 cm) from three diagonal locations within each of the 15 plots, and analysed it in the laboratory using a modified Moebius method. We then calculated the average soil organic carbon concentration for each land use.

Primary production

Net Primary Production (NPP) was estimated from NASA MODIS dataset using 1 km resolution MOD13 products between 2000 and 2013. One limitation of the low resolution of the products is that one pixel may contain several land use types. To deal with this problem, we proceeded, for each product, with an unmixing method under the linear mixture theory, assuming that each pixel observation y_p can be approximated by the weighted mean of the land use responses x_l with the area fraction f_{pl} of each land use in the pixel p: $y_p = \sum f_{pl} . x_l$ (Verbeiren et al., 2008). We obtained the f_{pl} values from the land use map and then solved the system of p equations to compute the set of x_l values for the five land use types using Matlab R2011a program (The Math Works, Inc., USA). We then calculated the average of NPP values (g C m^{-2} $year^{-1}$) between 2000 and 2013 for each land use.

Erosion and flood protection

Erosion control and flood regulation was deduced from the values of soil loss, infiltration rates and permeability for each land use type (Al Karkouri, 2003; Ortiz, 2010), using RUSLE model, and from erosion and soil protection maps (Aboulabbes et al., 2005).

Local climate regulation

Local climatic regulation was estimated through Land Surface Temperature (LST) considering that, for a land use type, high LST indicates low contribution to local climate regulation. To generate the LST map, we used a cloud free Landsat-5 TM image (path/row = 200/036) acquired on June 19, 2011 (10:40, GMT). The conversion of the spectral radiance L_λ to at-satellite brightness temperature *LST* was performed under the assumption of uniform emissivity, using pre-launch calibration constants (Landsat Project Science Office, 2002), such as: $LST = K_2 / \ln(K_1 / L_\lambda + 1)$, with $K_1 = 607.76$ and $K_2 = 1260.56$. From the generated LST map, we computed LST average values for each land use type.

Biomass accumulation

Biomass accumulation was obtained from empirical studies and inventories carried out in the study area and its vicinity: a forest management planning study for pines and Tetraclinis (Forest Administration of NE Morocco, 2012), agricultural yield reports for crops and cactus (Agricultural Technical Centre of Béni Boufrah, 2008), and estimations of biomass productivity for shrublands (Fechtal et al., 1995).

Water supply

The fraction of superficial and subterranean water available in the watershed, resulting from runoff, deep drainage and soil water content was deduced from the studies by Pascon and Wusten (1983) and Al Karkouri (2003) carried out in Béni Boufrah, and from the study by Bellot et al. (1999) carried out in a semiarid area of South-eastern Spain.

Specific richness, endemism, forage supply and AMP richness

These indicators were obtained through the fifteen 20 x 20 m plots established in the study area. The indicator values corresponded to averages of the three replicated plots per land use type. In each plot, specific richness, i.e., the number of vascular plants was recorded. Species cover was obtained using two 20 m linear transects per plot. Endemic species were identified using two widely used Moroccan bibliographic references: Fennane and Ibn Tattou (1998) and El Oualidi et al. (2012). We used the same plots to determine the number of endemic species for each land use type. Forage supply was estimated on the basis of the pastoral value (*PV*) expressed as percentage of vegetation cover: $PV = GVC * 0.1 * \sum_{i=1}^{n} Sc_i * Si_i$; where *GVC*: global vegetation cover (%), Sc_i : specific contribution of forage species *i*, Si_i: specific quality index (0 to 10) of forage species i. We used HCEFLCD (2008; 2013) to identify AMP species. Total cover of AMP by land use type was estimated from vegetation transects. We considered only shrubs with aromatic interest. Prickly pear and tree species, such as Red Barbary Cedar, Aleppo pine, kermes oak and wild olive, were considered of insignificant aromatic and medicinal interest in comparison to their dominant use in the study area (wood, forage, fruit…).

Food production

Average yield of cereal-almond crops and Cactus groves (kg ha^{-1}) was multiplied by their corresponding caloric value (Kcal per 100 g) to obtain nutritive value (10^6 Kcal/ha).

Aesthetic and traditional value

We used pictures illustrating the most relevant traits of the five land-use types evaluated. We used homogenous pictures and tried to control bias source by reducing the impact of external factors such as chromatic composition, light conditions, brightness, depth, date and time of the day (Kaltenborn and Bjerke, 2002; Arriaza et al., 2004). We asked stakeholders to classify them according to their aesthetic and traditional values. A score of 5 corresponded to the most beautiful or traditional land use, whereas a score of 1 indicated the least preferred and use. Average of the 67 scores was then calculated and attributed to each land use type.

Game abundance

Small and big game preferences for food and habitat were comparatively assessed for the five land uses type according to the opinion of 12 local hunters. A score of 5 was assigned to the most preferred land use, and the score of 1 to the least one. Scores were averaged to obtain the game abundance for each land use type.

Employment supply and Incomes generation

We used reports from forest and agriculture Administration departments, and interviews with local cooperatives and environmental NGOs to estimate these indicators. Employment supply (days ha^{-1} $year^{-1}$) corresponded to the main activities generated by each land use type: Planting for pine afforestation, fostering regeneration for Tetraclinis forests, farming cereal crops, production of AMP, honey and cactus cooperative activities. Income generation (US$ ha-1 year-1) corresponds to monetary revenues from pine wood, honey and aromatic and medicinal products, cactus fruits and other extracted products. For Tetraclinis woodlands, the indicator value corresponded to the equivalent monetary value of fire wood harvested by local populations.

Appendix 3. Ecosystem services weights derived from the preferences of each of the nine stakeholder sub-groups. Weights are ranked following the overall preferences of the 67 stakeholders. The most relevant differences in ecosystem services weights between sub-groups of a same group of stakeholders are highlighted in bold. See Table 3 for abbreviations.

Ecosystem service	*Scientists and managers*		*Collaborators*			*Direct users*			
	Scientists	*Managers*	*Authority and representatives*	*NGOs members*	*Facilitators*	*Farmers*	*Members of cooperatives*	*Other users*	*Inhabitants*
Water supply (PS)	0,074	0,092	0,086	0,079	0,095	0,096	0,090	0,091	0,092
Erosion protection (RS)	0,098	0,075	0,104	0,087	0,084	0,090	0,070	0,077	0,100
Flood protection (RS)	0,090	0,073	0,099	0,089	0,075	0,096	0,075	0,080	0,097
Soil fertility (SS)	0,068	0,061	0,077	0,082	0,060	0,076	0,077	0,089	0,065
Food provision (PS)	0,055	0,067	0,070	0,062	0,082	0,073	0,072	0,076	0,076
Local climate regulation (RS)	0,071	0,061	0,083	0,067	0,063	0,072	0,061	0,067	0,080
Primary production (SS)	0,064	0,064	0,063	0,079	0,055	0,071	0,068	0,083	0,057
Biomass production (PS)	0,045	0,060	0,052	0,047	0,063	0,062	0,057	0,053	0,054
Forage supply (PS)	0,047	0,057	0,047	0,047	0,062	0,052	0,053	0,053	0,054
AMP richness (PS)	0,044	0,066	0,041	0,042	0,058	0,049	0,054	0,052	0,055
Specific richness (B)	0,064	0,061	**0,044**	**0,063**	**0,044**	**0,057**	**0,041**	**0,040**	**0,051**
Incomes generation (EB)	0,049	0,046	0,033	0,040	0,051	0,032	0,057	0,044	0,040
Game abundance (B)	0,051	0,054	**0,033**	**0,047**	**0,043**	**0,051**	**0,039**	**0,037**	**0,041**
Employment supply (EB)	0,044	0,043	0,033	0,033	0,049	0,036	0,061	0,047	0,043
Endemism (B)	0,056	0,051	**0,033**	**0,053**	**0,040**	**0,047**	**0,038**	**0,030**	**0,039**
Traditional value (CS)	0,041	0,034	0,053	0,046	0,038	0,023	0,045	0,040	0,031
Aesthetic value (CS)	0,039	0,033	0,049	0,038	0,037	0,018	0,043	0,039	0,025

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